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WIND-TUNNEL INVESTIGATION OF SIMULATED HELICOPTER ENGINE EXHAUST INTERACTING WITH WINDSTREAM

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16. Abstract
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SUMMARY

A wind-tunnel investigation of the windstream—engine-exhaust flow interaction on a light observation helicopter model has been conducted in the Langley V/STOL tunnel. This program was sponsored jointly by the U.S. Army Aviation Systems Command and National Aeronautics and Space Administration. The investigation utilized flow-visualization techniques to determine the cause of exhaust-shield overheating during cruise and to find a means of eliminating the problem. Exhaust-flow attachment to the exhaust shield during cruise was found to cause the overheating. Several flow-altering devices were evaluated to find a suitable way to correct the problem. A flow deflector located on the model cowling upstream of the exhaust in addition to aerodynamic shield fairings provided the best solution. Also evaluated was a heat-transfer concept employing pin fins to cool future exhaust hardware. The primary flow-visualization technique used in the investigation was a newly developed system employing neutrally buoyant helium-filled bubbles. The resultant flow patterns were recorded on motion-picture film and on television magnetic tape.

INTRODUCTION

A problem encountered by a current light observation helicopter is that of engine-exhaust-shield overheating during cruise. The structural damage occurring because of this problem has resulted in excessive maintenance costs and also has created a safety hazard for crew members. Flight-test data illustrating the magnitude and extent of the overheated areas occurring on the helicopter are presented in reference 1. The affected area is shown in figure 1.

The present investigation was conducted to identify the cause of the exhaust-shield overheating and to evaluate methods for its elimination. Since the overheating was believed to be caused by the flow attachment of the hot-exhaust gases to the external surfaces of the shield and not by inadequate heat-transferring materials, the problem was treated from an aerodynamic viewpoint. The test program consisted of investigating a number of flow-altering devices for their ability to prevent exhaust-flow attachment to the exhaust shield. Devices were designed both to change the windstream speed or direction just upstream of the exhaust shields and to directly alter the exhaust-flow characteristics within the exhaust ducting.

The primary simulation parameter, the ratio of effective windstream to exhaust velocity, was varied from 0 to approximately 1.4. The windstream dynamic pressure was limited to 622 N/m^2 (13 lb/ft^2). The angle-of-attack (α) range was 0° to -13°, and the model sideslip (β) range was 10° to -10°.

Flow-visualization techniques were used to identify the flow paths and their interactions with free-stream flow; the types of flow-visualization techniques used were: wool tufts, kerosene smoke, and neutrally buoyant helium-filled soap bubbles. The resultant flow patterns were recorded on motion-picture film and television magnetic tape. Some of the recordings are presented in film supplement L-1139 and are available on request. A request card and a description of the film are included at the back of this document. The development of the helium-bubble generator system, which includes a unique set of equipment for bubble production, bubble illumination, and video recording, is described in reference 2.

SYMBOLS

The symbols used for physical quantities defined in this paper are given in both the U.S. Customary Units and the International System of Units (SI). Factors relating these two systems of units are presented in reference 3.

$q_{exhaust}$ exhaust dynamic pressure, N/m^2 (lb/ft^2)

q_∞ free-stream dynamic pressure, N/m^2 (lb/ft^2)

V_{eff} ratio of effective windstream velocity to engine-exhaust velocity, $\sqrt{\frac{q_\infty}{q_{exhaust}}}$

V_j jet-exhaust velocity, m/sec (ft/sec)

V_∞ free-stream velocity, m/sec (ft/sec)

α angle of attack measured between free-stream velocity direction and the model baseline, deg

β sideslip angle (positive with nose left when looking upstream), deg

APPARATUS

Model

A photograph of the OH-58A helicopter being studied in this investigation is shown in figure 2. The model (fig. 3) tested in the V/STOL tunnel is composed of the entire engine cowling and forward fairing from the OH-58A helicopter. The exhaust pipes, exhaust shields, and internal-exhaust collector (fig. 4) on the model are also flight hardware. The rotor was not installed on the model because the full-scale rotor diameter is greater than the tunnel width. It was not considered necessary to include the effects of the rotor for the purposes of this investigation. Analysis of the rotor downwash (ref. 4) indicates that at the cruise condition, the tip vortex will pass high enough above the cowling to have little influence upon the exhaust at the pipe exit. This assumption is supported by the symmetric pattern of external burning evident on the left and right exhaust shields of these helicopters; the pattern indicated little influence from the asymmetric rotor downwash.

The exhaust gas was simulated by compressed air as shown in figure 5. Ambient-temperature air was used in the simulation.

Flow Modification Hardware

Drawings and photographs of the flow modification hardware used in the present investigation are presented in the following figures:

	Figure
Antiswirl vanes in exhaust pipe	6
Flange covering gap between pipe and shield, with 1.3-cm (0.5-in.) overhang around shield	7
Exhaust deflector pipes, 0°, 10°, 20°	8
Flow control collar	9
Flat plate	10
Flow turning ramp	11
Flow deflector	12
Flow deflector and aerodynamic shield fairings	13
Pin-fin exhaust pipe	14
Pin-fin pipe plus curved plate	15
Pin-fin pipe plus flat plate	16

With the exception of the wooden pins on the pin-fin pipe, all modifications were constucted of sheet aluminum.

Flow-Visualization Equipment

The primary investigatory equipment was a helium-bubble generator system. (See ref. 2.) This system is useful for airflow visualization when flow temperatures are less than 54° C (130° F) and flow velocities less than 61 m/sec (200 ft/sec). Figure 17 shows the general arrangement of this system which includes a bubble-generating subsystem, a bubble-illumination subsystem, and a video-recording subsystem. By filling soap bubbles with helium, the bubbles can be made neutrally buoyant, a condition which enables the bubbles to follow the flow streamlines. Each source of bubble can be regulated to produce bubbles up to 0.32 cm (0.125 in.) in diameter at a maximum rate of approximately 2000 bubbles per minute. The bubbles are released upstream of the model and are illuminated by a high-powered light source located downstream of the model. As the bubbles pass over the model, they are photographed from the side and/or top of the test section. The model was painted black to provide a nonreflecting background for high-quality video pickup of the bubble streaks. For improved bubble visualization, three special video features were sometimes used: (1) reversal of the video polarity to observe the bubbles as dark streaks on a white background; (2) video-tape instant replay; and (3) variable slow-motion replay.

At times, when it was necessary to provide more light reflection than the bubbles could produce, kerosene smoke was released into the flow instead of the bubbles. The same video recording equipment was used to photograph these scenes.

Wool tufts placed on the model also gave some insight into the flow interactions. In particular, this technique was useful in studying the flow inside the exhaust pipes and along the cowling surface downstream of the exhaust shields.

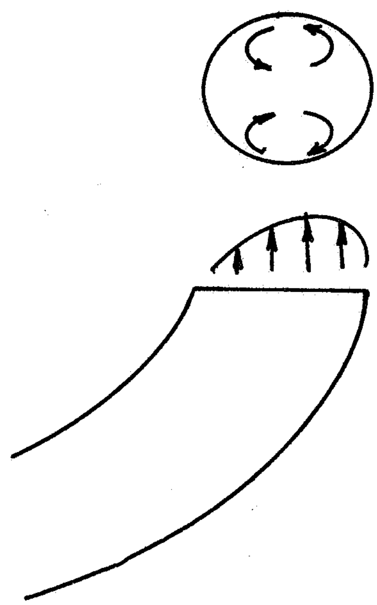
TESTS

For the V/STOL tunnel tests, the primary simulation parameter was the ratio of effective windstream velocity to exhaust velocity V_{eff}. Since the exhaust-heating problem was known to occur at cruise conditions for this helicopter configuration, a range of V_{eff} from 0 to 1.4 was tested. Although tunnel dynamic pressure was as high as 622 N/m^2 (13 lb/ft^2), requirements for detailed smoke and bubble visualization dictated that most of the tests be made at a windstream dynamic pressure of 48 N/m^2 (1 lb/ft^2). Previous research (ref. 5) has shown that when flow temperatures or velocities cannot be reproduced, realistic flow simulation can be obtained by reproduction of the ratio of effective windstream velocity to exhaust velocity V_{eff}. The angle-of-attack range was 0° to -13° and the model sideslip angle was varied from 10° to -10°.

Each of the proposed modifications listed in the previous table was installed and systematically evaluated over the effective velocity ratio range. Combinations of the antiswirl vanes with other modifications were also studied. These vanes were included on all but the deflected exhaust and pin-fin pipes.

RESULTS AND DISCUSSION

The photograph and sketch presented in figure 18 illustrate the exhaust-flow characteristics inside the engine-exhaust pipe. As viewed from above the model, a clockwise swirl existed in the left exhaust flow. The swirl is noticeable in the nozzle efflux as shown in figure 19. The right-hand exhaust had a counterclockwise swirl. Swirling motion in the exhaust flow before it is ejected to the free stream is expected. As noted in reference 6, flow in curved pipes is characterized by secondary flow patterns as shown in sketch (a).



Sketch (a)

The exhaust system investigated has more complex curved ducting to the exhaust outlet. As a result, secondary flow patterns can be expected to be significant. Also, the nonuniform flow and flow separation inside the exhaust collector led to a pressure recovery at the exhaust exit of only about 60 percent.

Exhaust-flow attachment to the exhaust shield was observed (fig. 20) by insertion of the smoke and bubble heads into the exhaust exit. This attachment was seen over an effective velocity ratio range from 0.6 to 1.0. After documentation of the manner of flow attachment on the original exhaust, the flow modifications hardware previously described in figures 6 to 16 was mounted and evaluated by use of smoke and/or neutrally buoyant bubble-flow visualization techniques. The evaluations as documented in figures 18 to 27 require the sketches presented with each figure to illustrate the three-dimensional character of the flow patterns observed.

The following devices offered little or no improvement for correcting the exhaust impingement:

(1) Antiswirl vanes in exhaust stack

(2) 0°, $\pm 10^{\circ}$, and $\pm 20^{\circ}$ exhaust-deflector pipes

(3) Flange covering the gap between exhaust stack and shield and overhanging the shield by 1.3 cm (0.5 in.)

The flow-control collar (fig. 9) was moderately successful in eliminating the exhaust attachment. It worked by collecting windstream air and directing the air through a converging section at the upper outboard surface of the exhaust shield. The air blew the exhaust back up toward the pipe exit, but did not completely eliminate the exhaust attachment. (See fig. 21.)

The next series of modifications was aimed at lessening the influence of the windstream on the exhaust so that the exhaust flow would penetrate further upward. This additional penetration would make it possible for the exhaust to mix fully with the windstream. First, a flat rectangular plate (fig. 10) was placed on the end of a pole and maneuvered upstream of the exhaust. With the plate in the vertical position, the windstream was blocked and the exhaust penetrated well into the airstream overhead. (See fig. 22.) The flow separation on the downstream side of the plate induced exhaust flow forward toward the plate.

A modification of the flat plate was the flow-turning ramp (fig. 11). By turning the windstream before it reached the exhaust, this modification decreased somewhat the exhaust attachment while reducing the windstream separation that had occurred on the downstream side of the flat plate. (See fig. 23.)

The flow deflector (figs. 12 and 13) produced the best results in eliminating the exhaust attachment. As a further refinement of the flat plate and turning ramp, the flow deflector eliminated the problem over the entire yaw and pitch range as well as over the effective velocity ratio range (fig. 24). The deflector turns the free-stream flow upward at the exhaust-exit height. A deflector with the tips cut off at a 45° angle was inferior to one with squared-off tips. This result indicated that the strong tip vortices from the squared-off deflector are a significant part of the solution. Both features, vortices and flow turning, facilitated exhaust penetration into the wind flow above the cowling. To reduce flow separation inherent with the present engine exhaust shields, fairings were added fore and aft of the shield. (See fig. 13.) This arrangement allowed smoother flow through the slot between the deflector and shield as well as reduced windstream separation aft of the shield. (See fig. 25.) The improved flow pattern allowed by the fairings tends to offset the drag loss that might be incurred by the flow deflector.

The pin-fin pipe (fig. 14) was tested in order to study the external aerodynamics of a device utilizing a simple heat-transfer technique. Pins attached to the external surface of the pipe served to greatly increase (by 50 percent or more) the radiating surface area for heat transfer to the passing wind flow which would thereby cool the outside of the pipe. For evaluating external aerodynamics, wooden pins were sufficient. As shown in figure 26, flow passed satisfactorily over the pipe, except in the wake separation region. Separation would result in poor heat transfer since flow velocities there are very low and not as effective in removing heat from the pipe. To alleviate this problem, two attempts were made to reduce the wake separation; a curved plate (fig. 15) and a flat plate (fig. 16) were separately affixed. Both achieved some reduction of the flow separation although it was not possible to document the effect with photography. The curved plate appeared to be somewhat less desirable because of the flow separation it incurred. (See fig. 27.)

CONCLUSIONS

A wind-tunnel investigation of the windstream—engine-exhaust flow interaction on a light observation helicopter model gives the following results:

1. Exhaust flow attaches to the exhaust shield when the ratio of effective wind velocity to exhaust velocity is greater than 0.6.

2. Exhaust-flow attachment to the exhaust shield is best eliminated by use of a flow deflector which diverts windstream flow upstream of the exhaust and vortices formed by the flow deflector provide additional upward windstream flow at the outboard region of the exhaust shield.

3. Aerodynamic fairings around the exhaust shield reduce wind-flow separation at the exhaust shields and make the flow deflector more effective.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., February 8, 1974.

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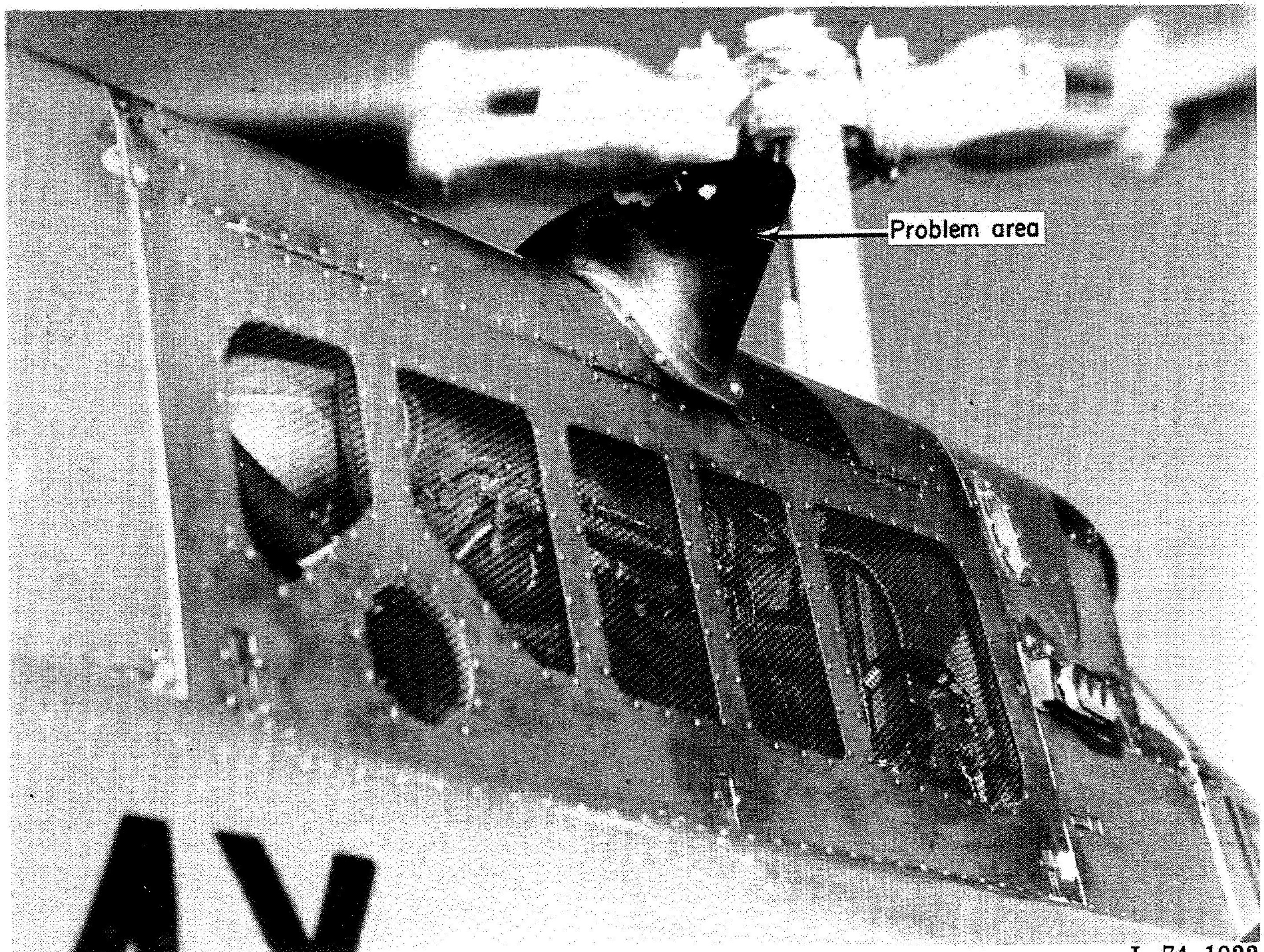

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Figure 1.- Exhaust shield burned by exhaust gas.

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Figure 2.- Helicopter under study.

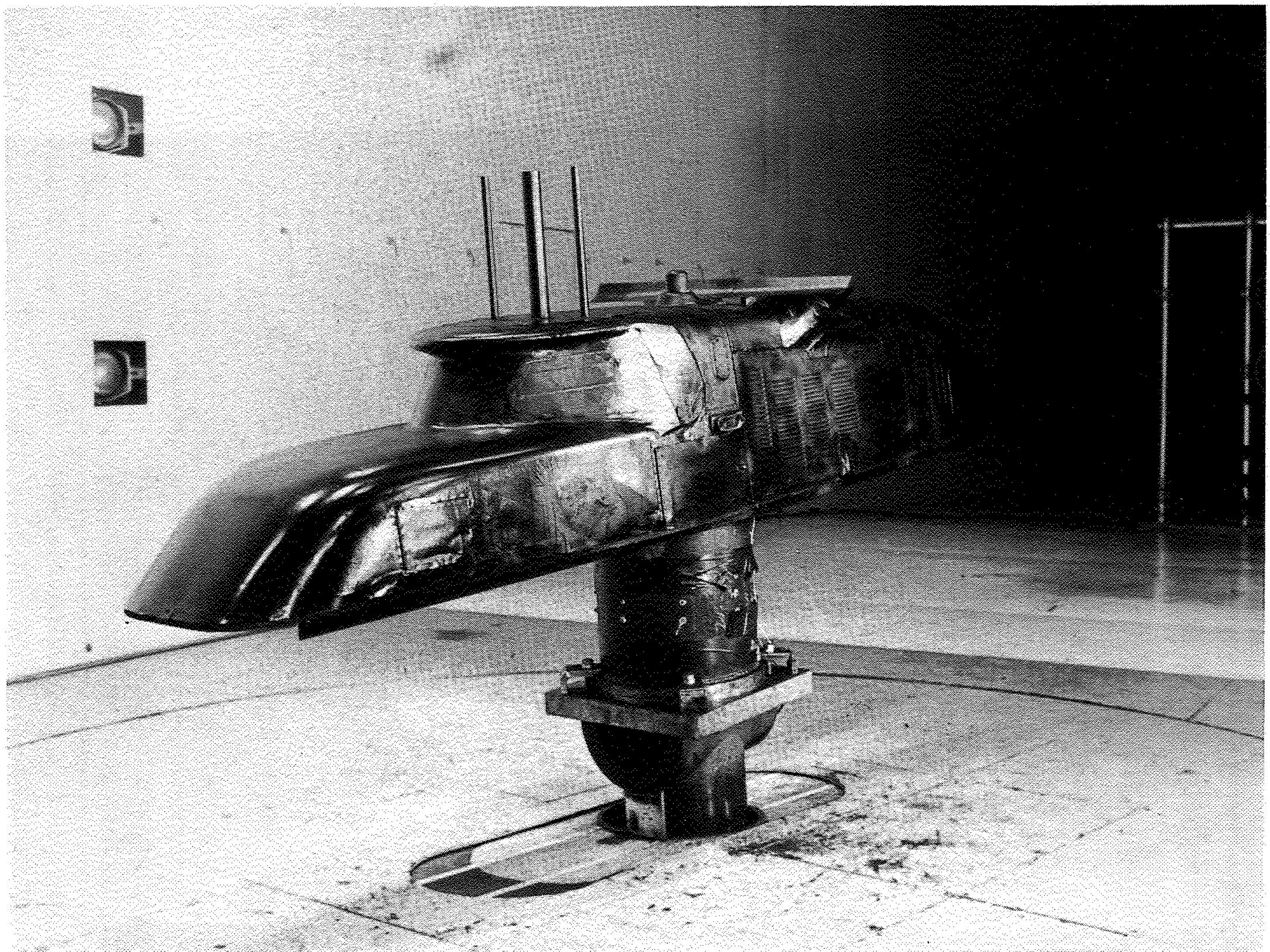

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Figure 3.- Installation of helicopter main pylon in the Langley V/STOL tunnel.

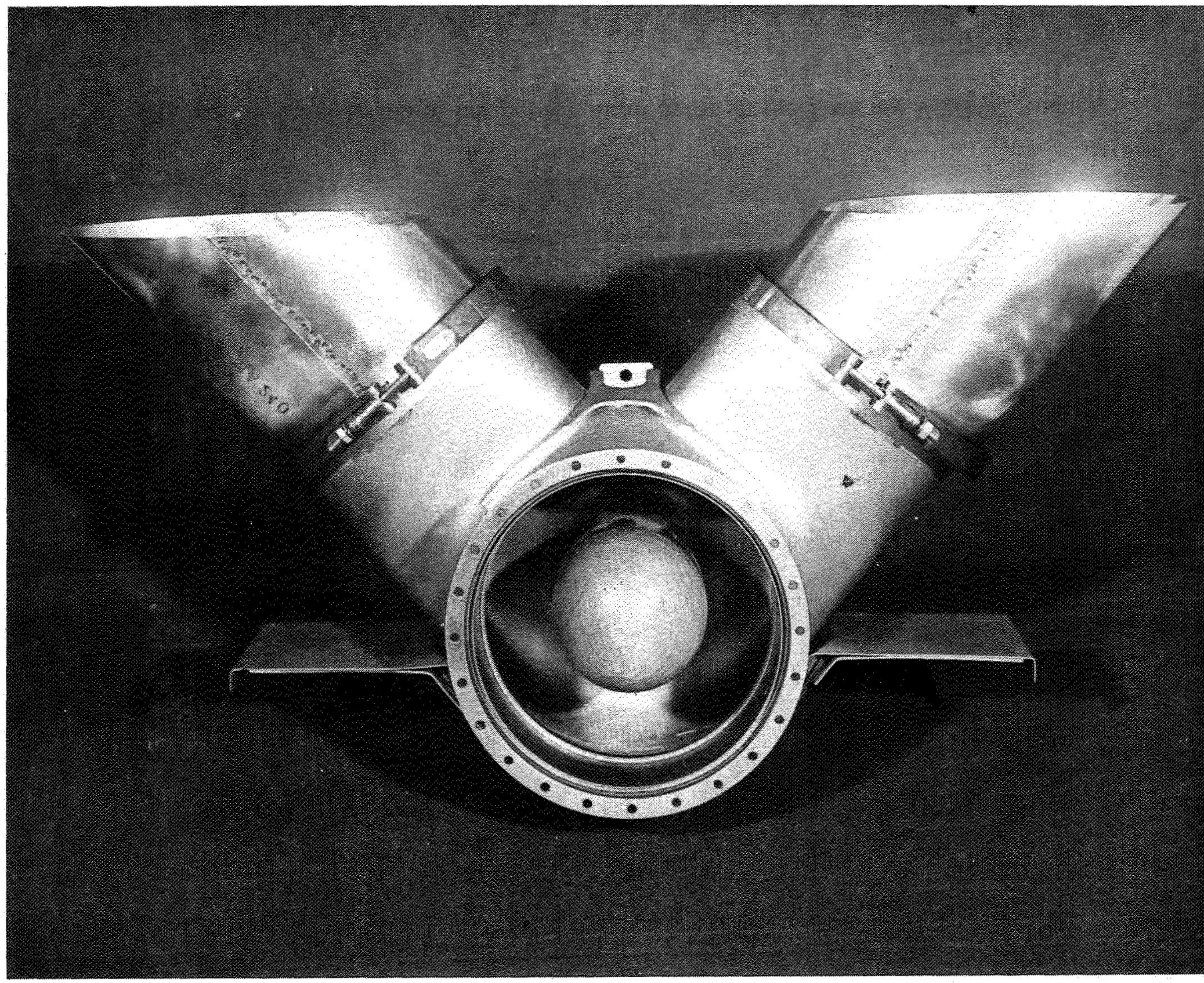

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Figure 4.- Helicopter-exhaust collector assembly.

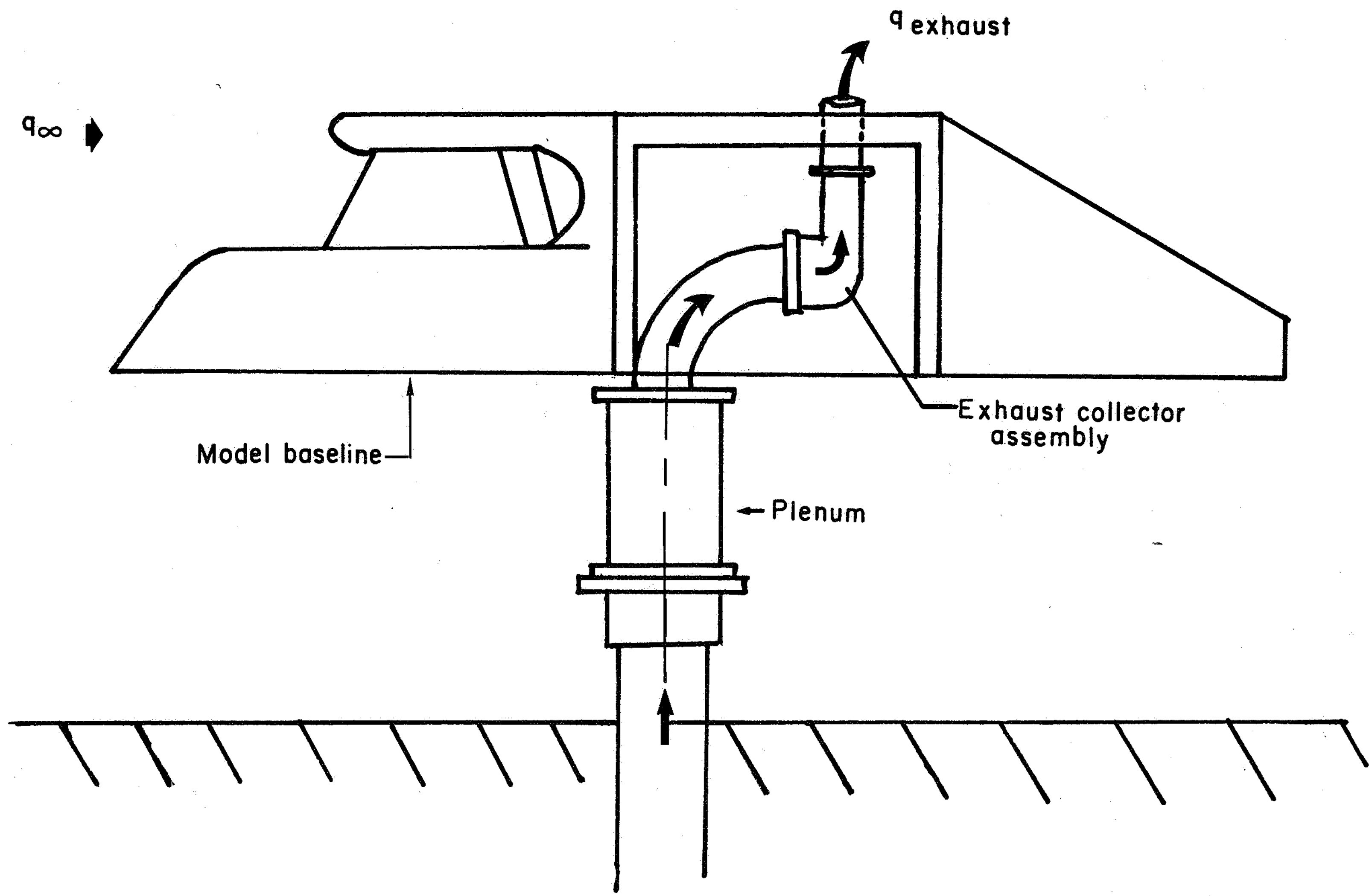

Figure 5.- Schematic of air-supply system connected to engine-exhaust stacks.

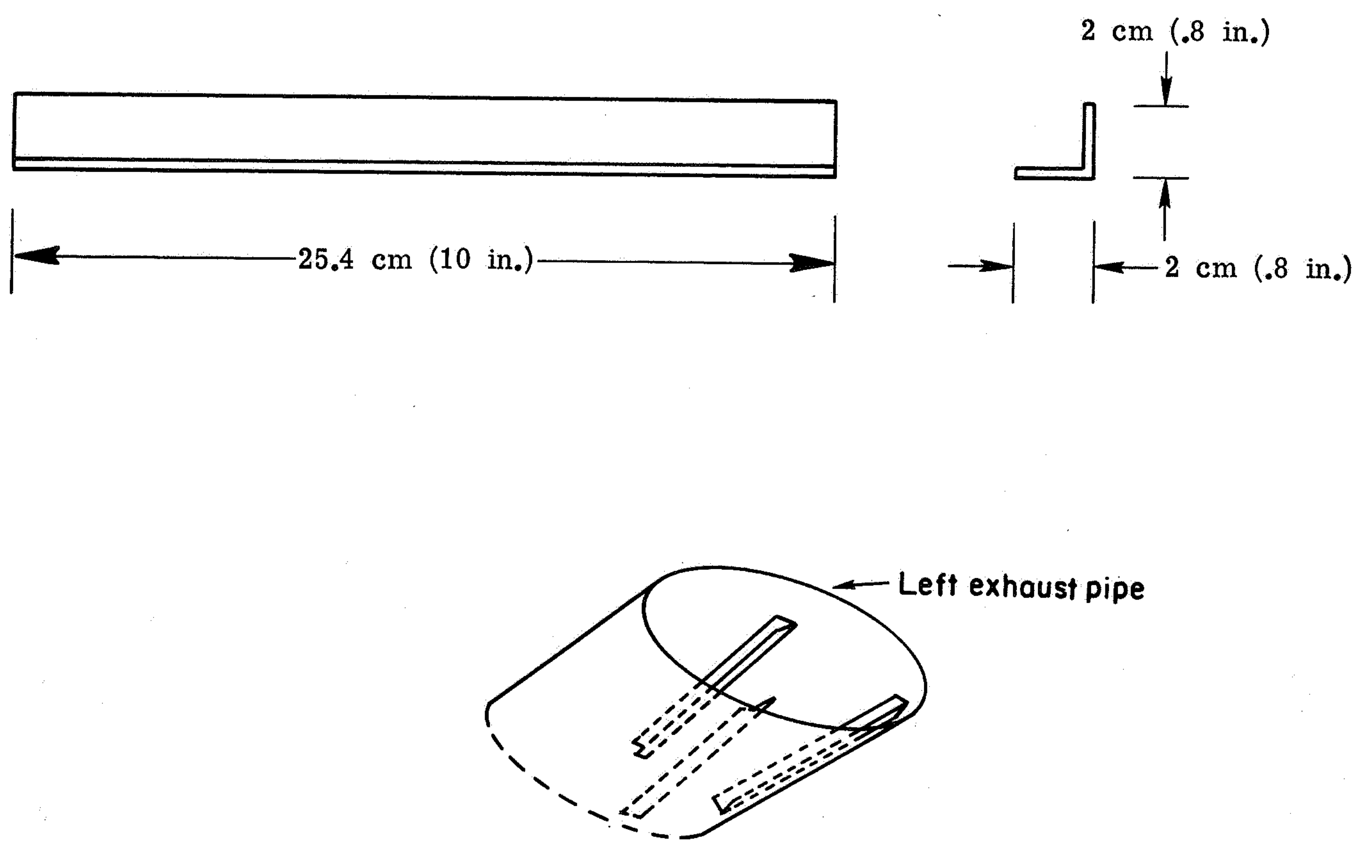

Figure 6.- Antiswirl vanes.

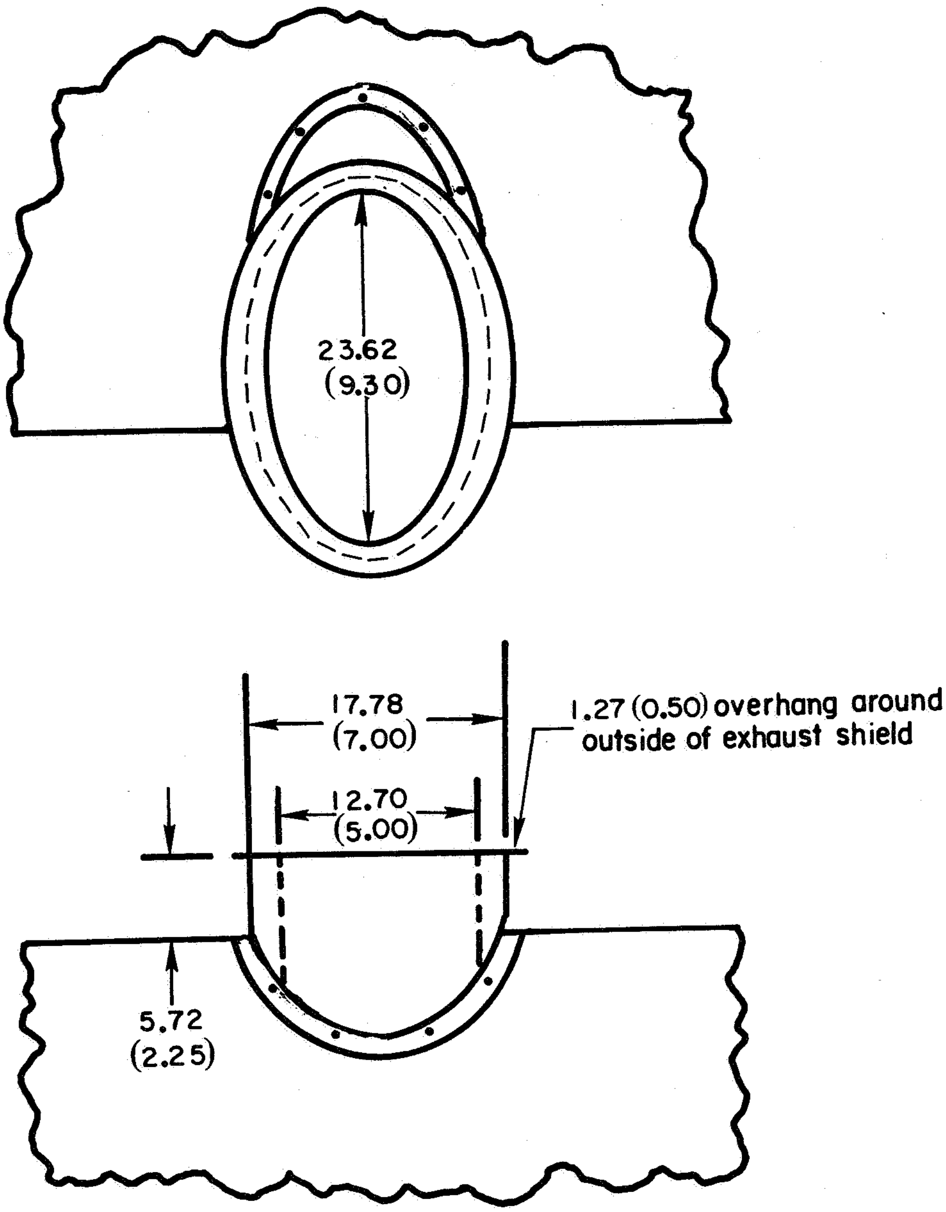

Figure 7.- Flange covering gap between shield and stack. Dimensions are given in centimeters (inches).

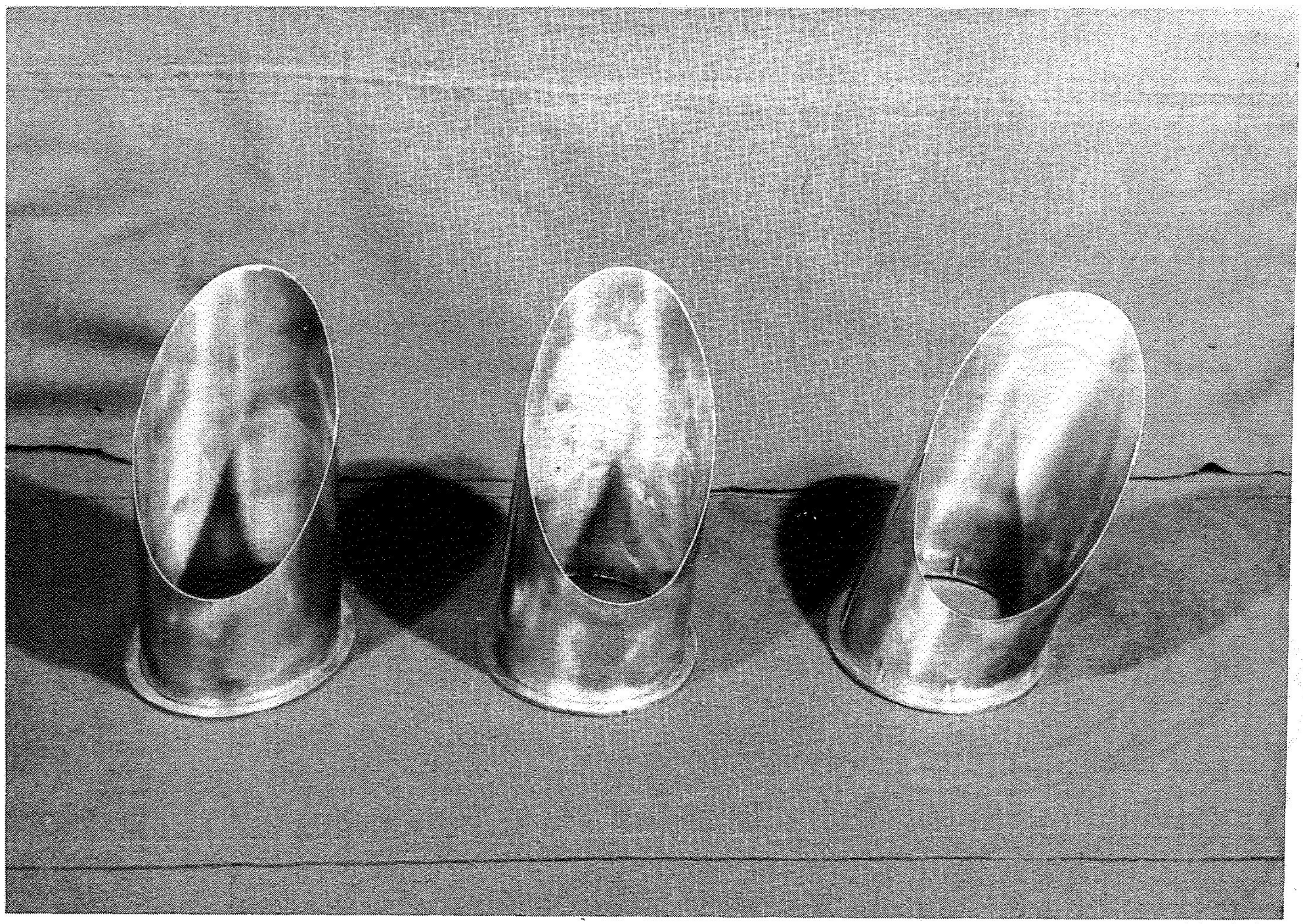

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Figure 8.- Exhaust deflector pipes (stacks).

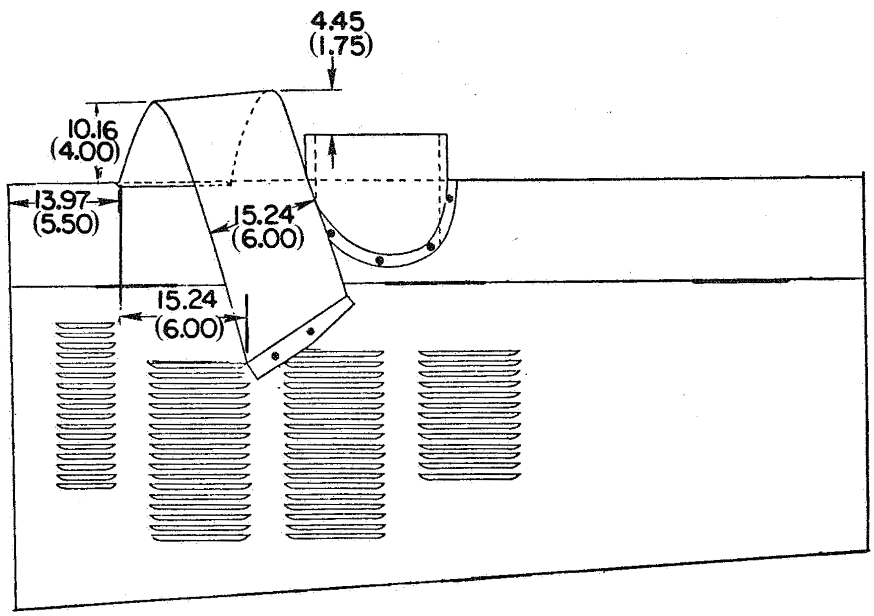

Figure 9.- Flow control collar. Dimensions are given in centimeters (inches).

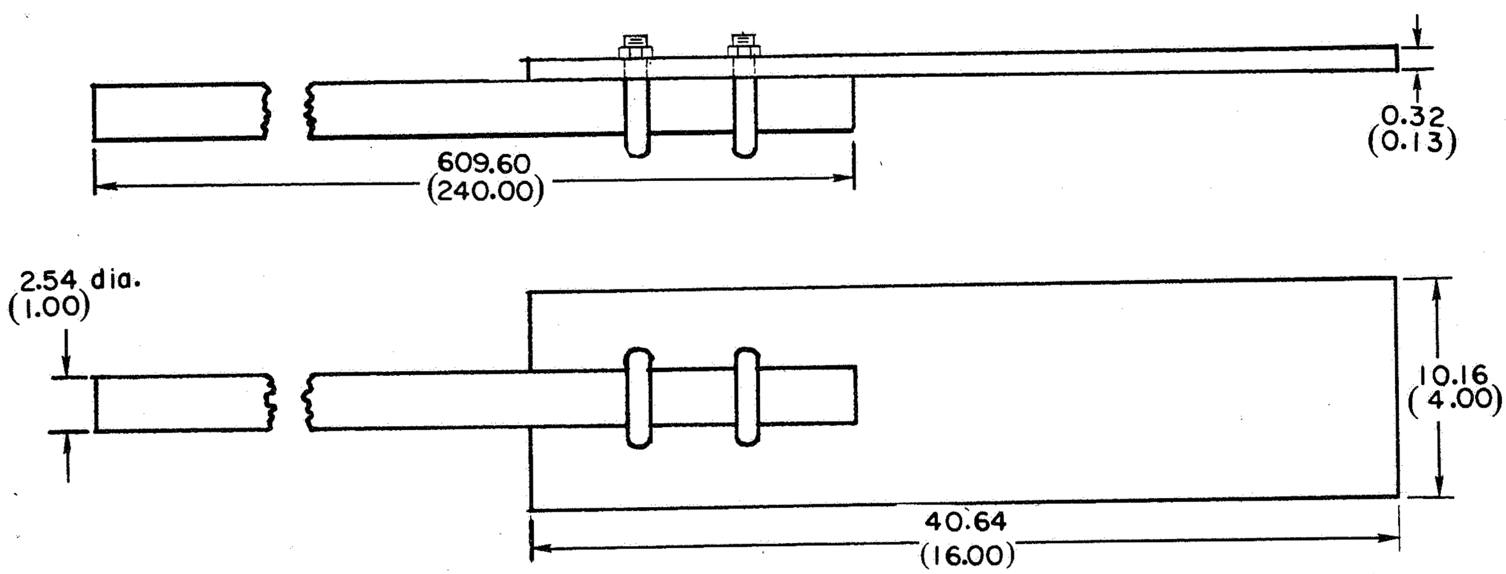

Figure 10.- Flat plate. Dimensions are given in centimeters (inches).

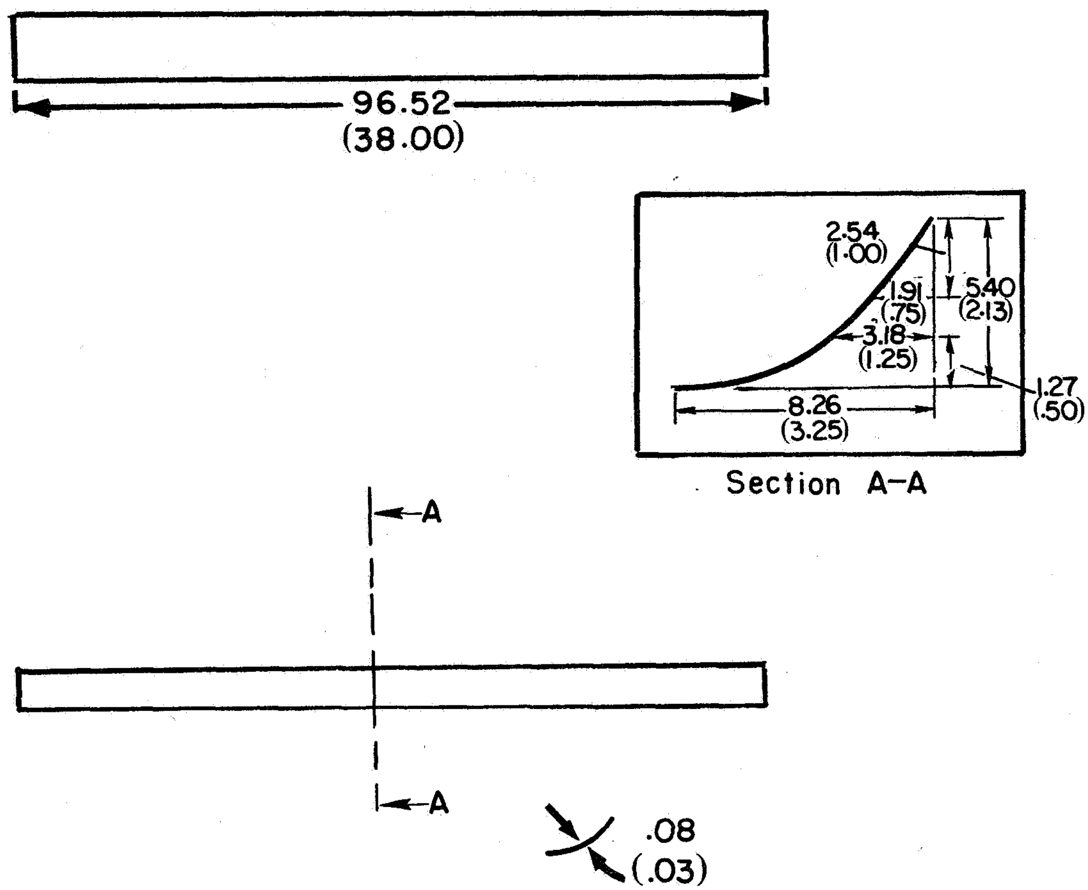

Figure 11.- Flow turning ramp. Dimensions are given in centimeters (inches).

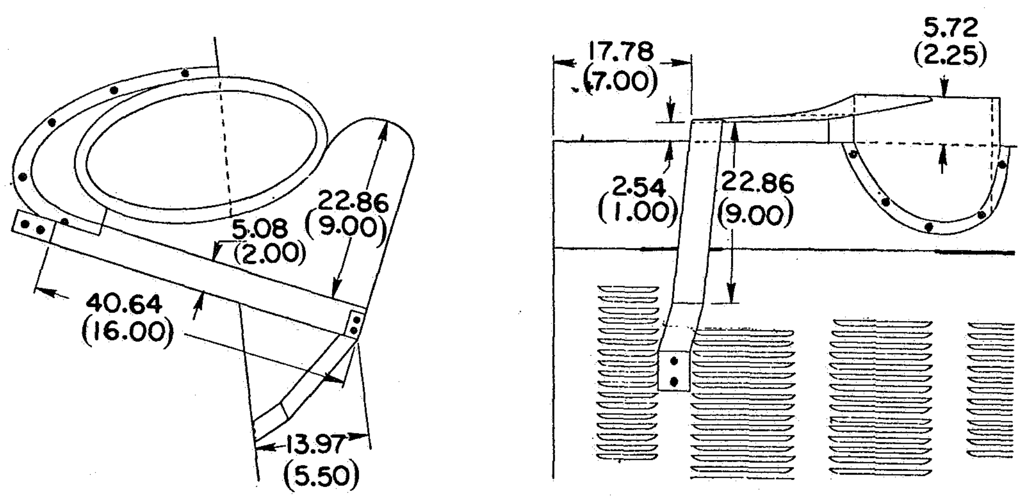

Figure 12.- Flow deflector. Dimensions are given in centimeters (inches).

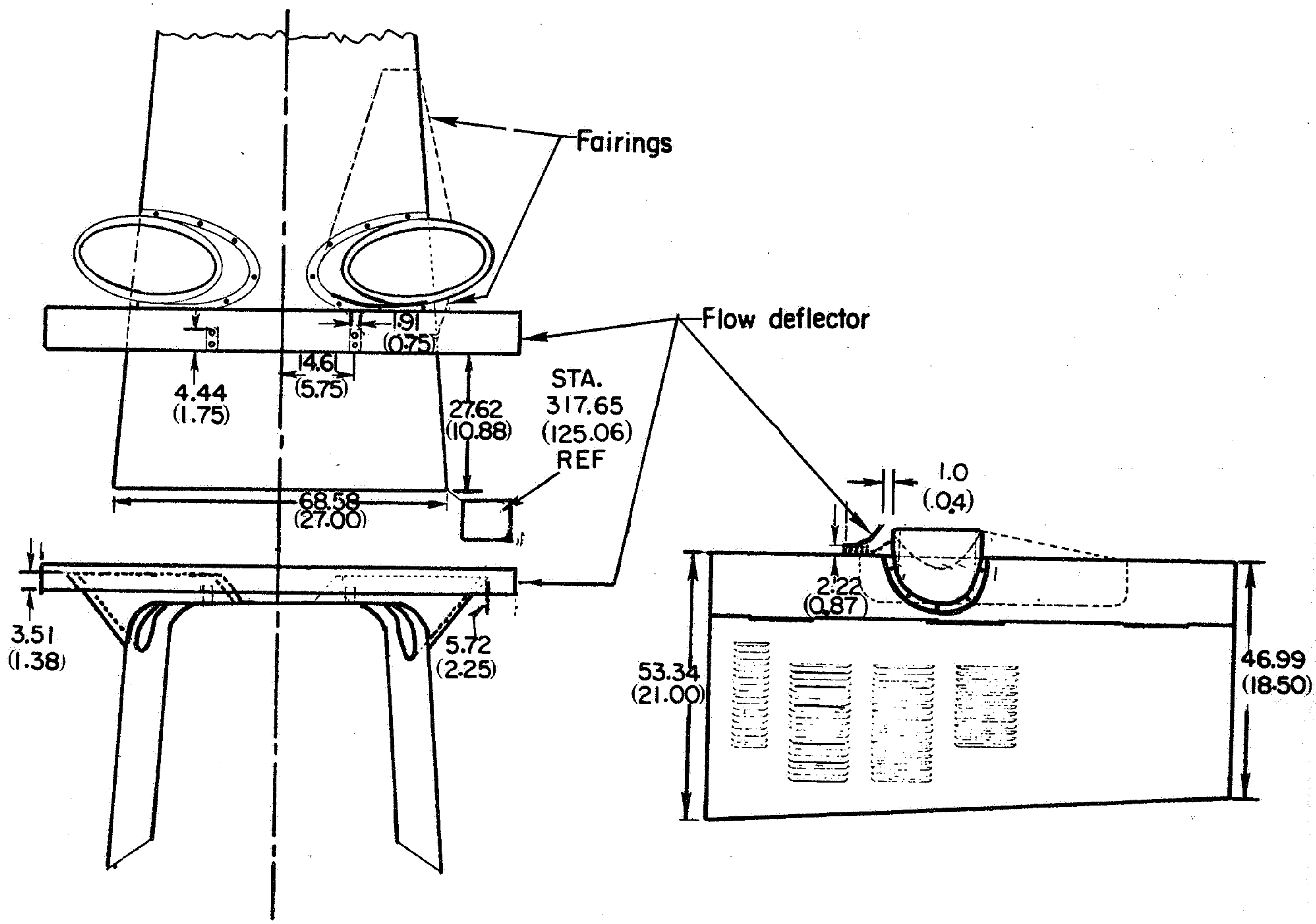

Figure 13.- Flow-deflector installation with shield fairings. Dimensions are given in centimeters (inches).

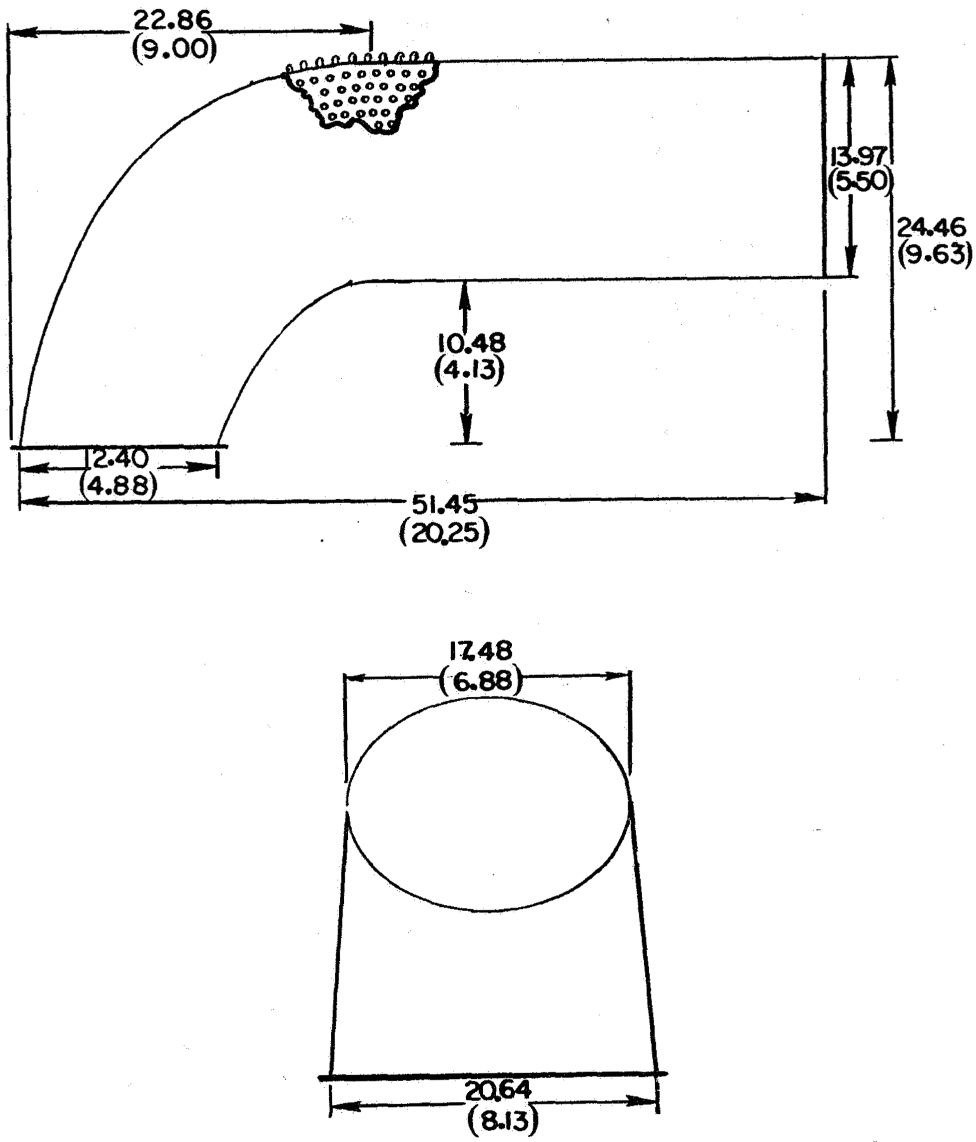

Figure 14.- Pin-fin exhaust pipe. Dimensions are given in centimeters (inches).

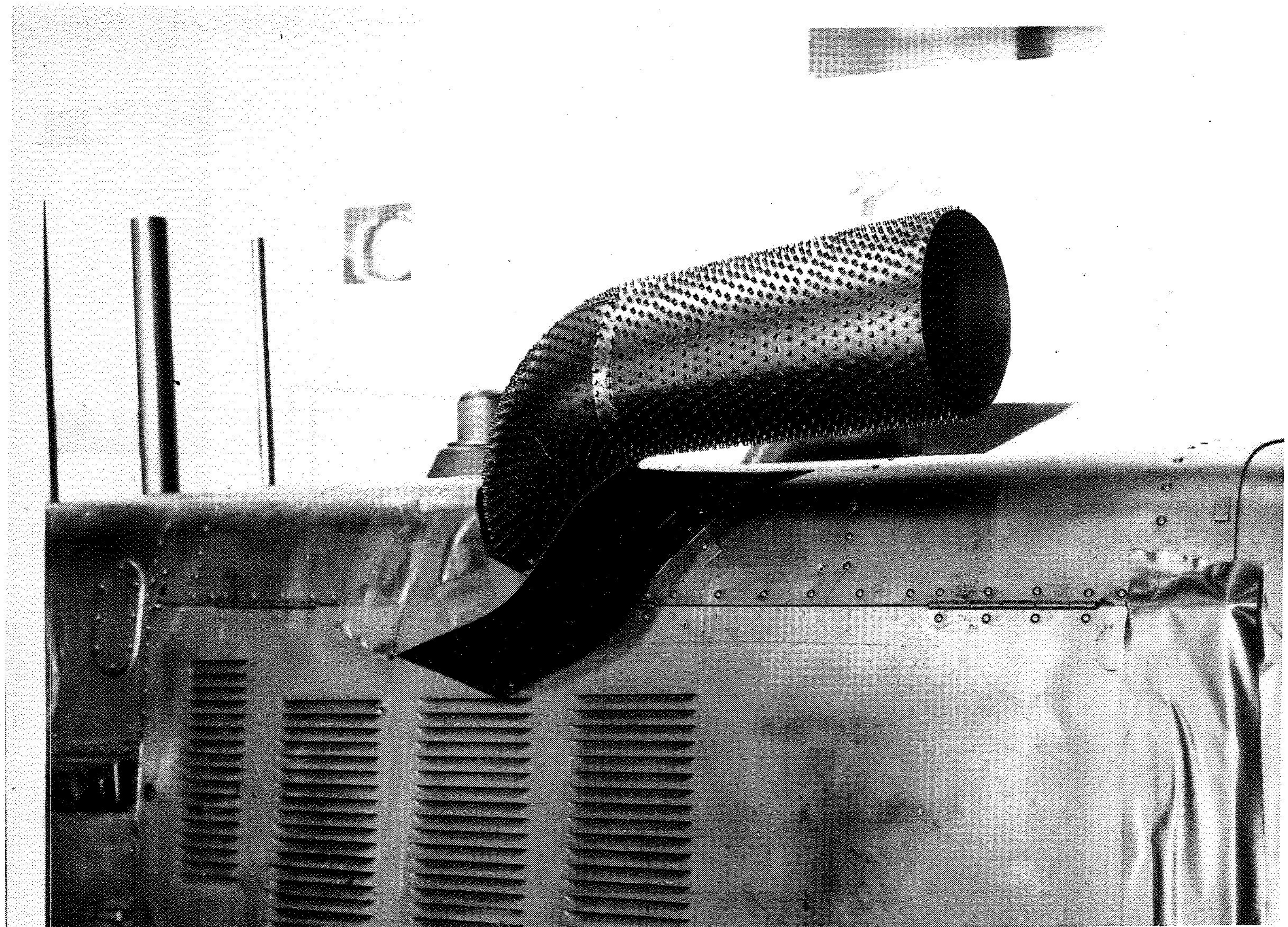

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Figure 15.- Pin-fin pipe with curved plate.

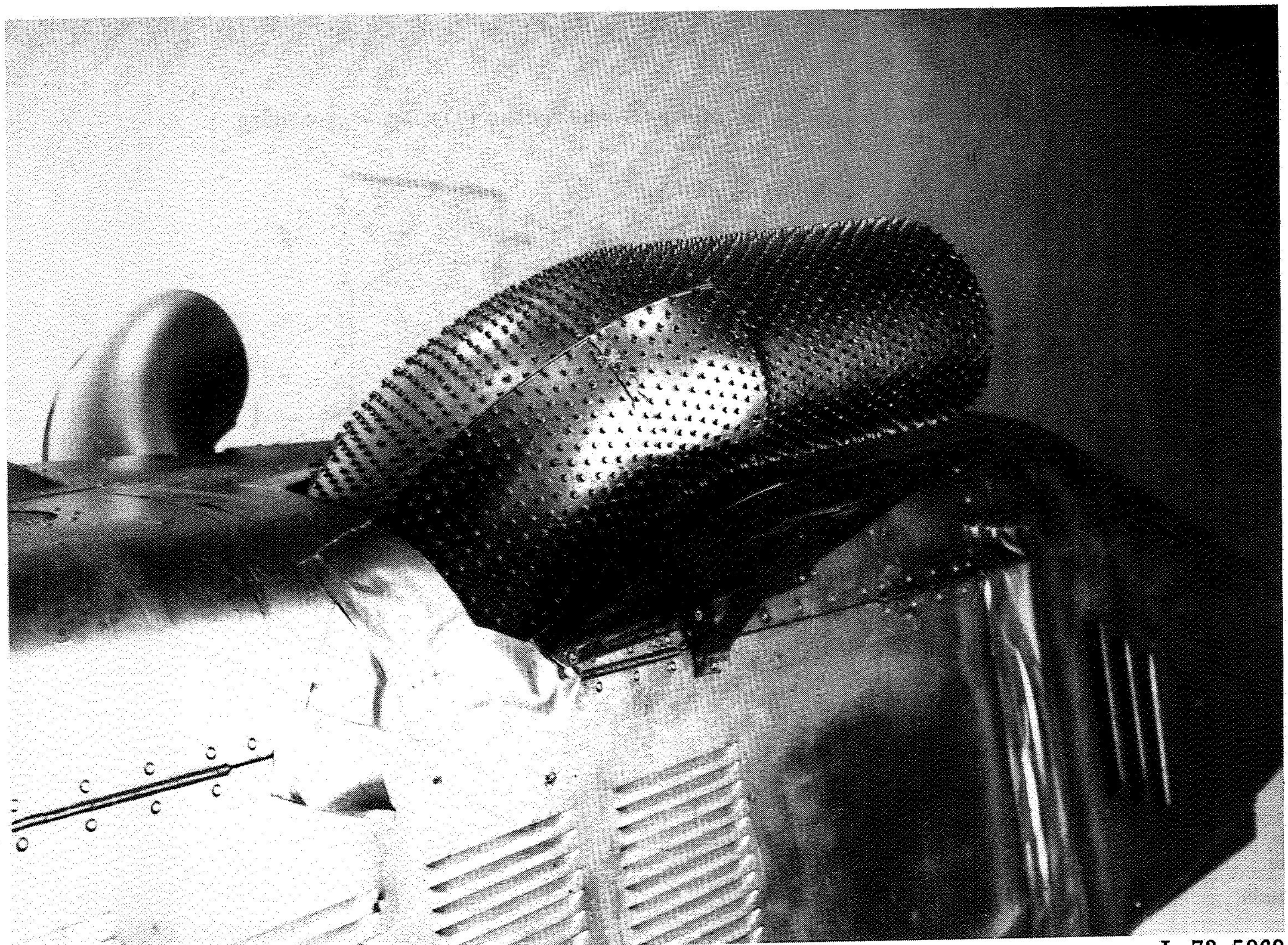

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Figure 16.- Pin-fin pipe with flat plate.

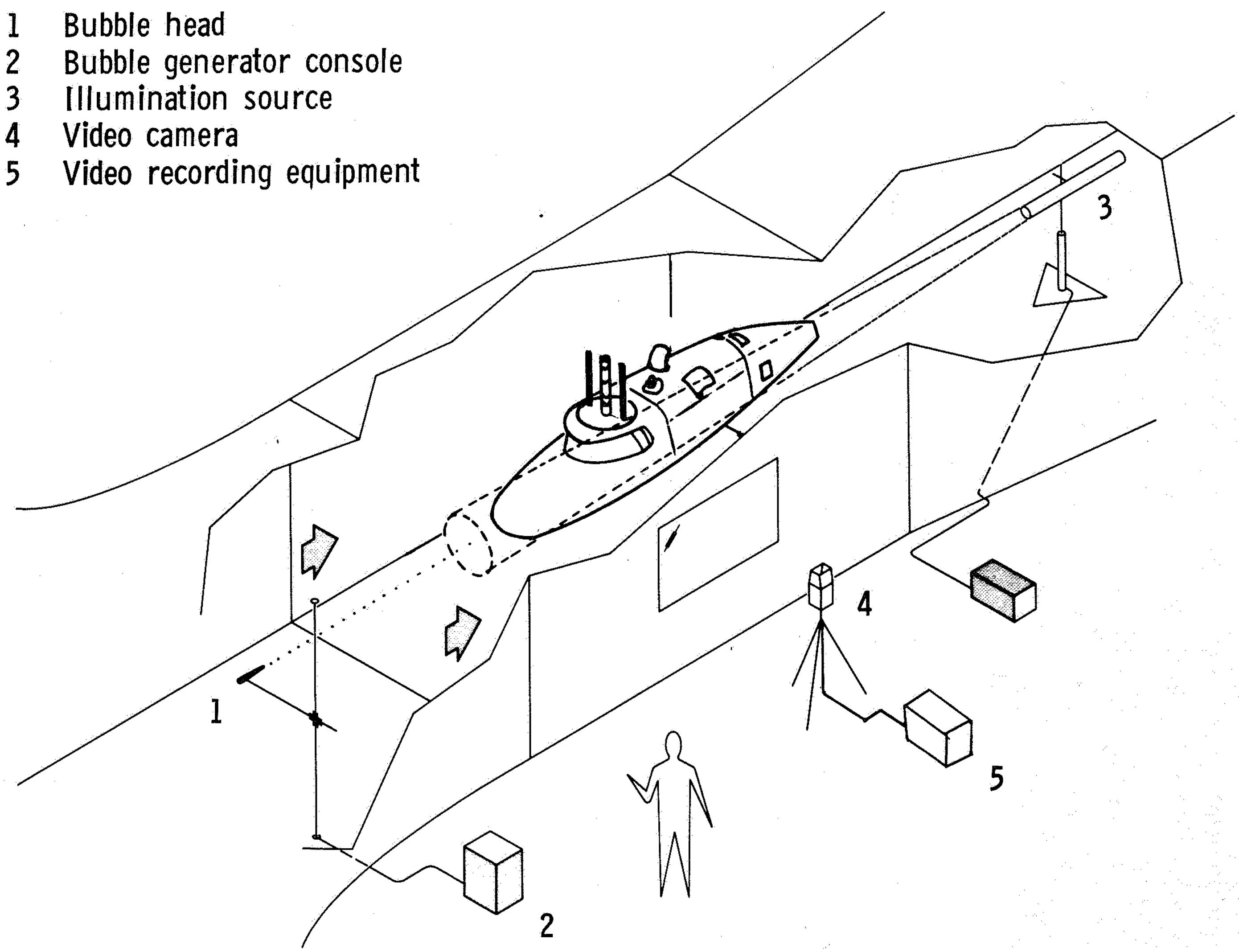
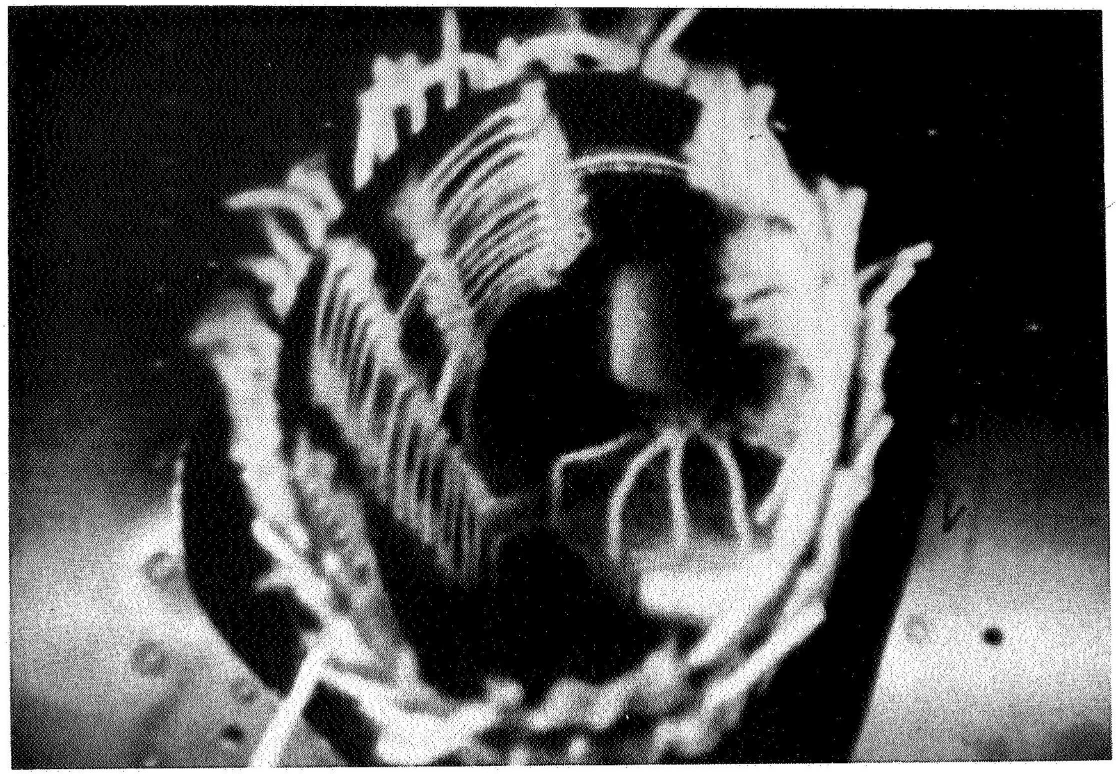


Figure 17.- General arrangement of airflow visualization system.



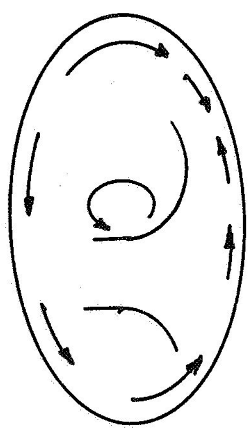


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Figure 18.- Tuft patterns in "static test."

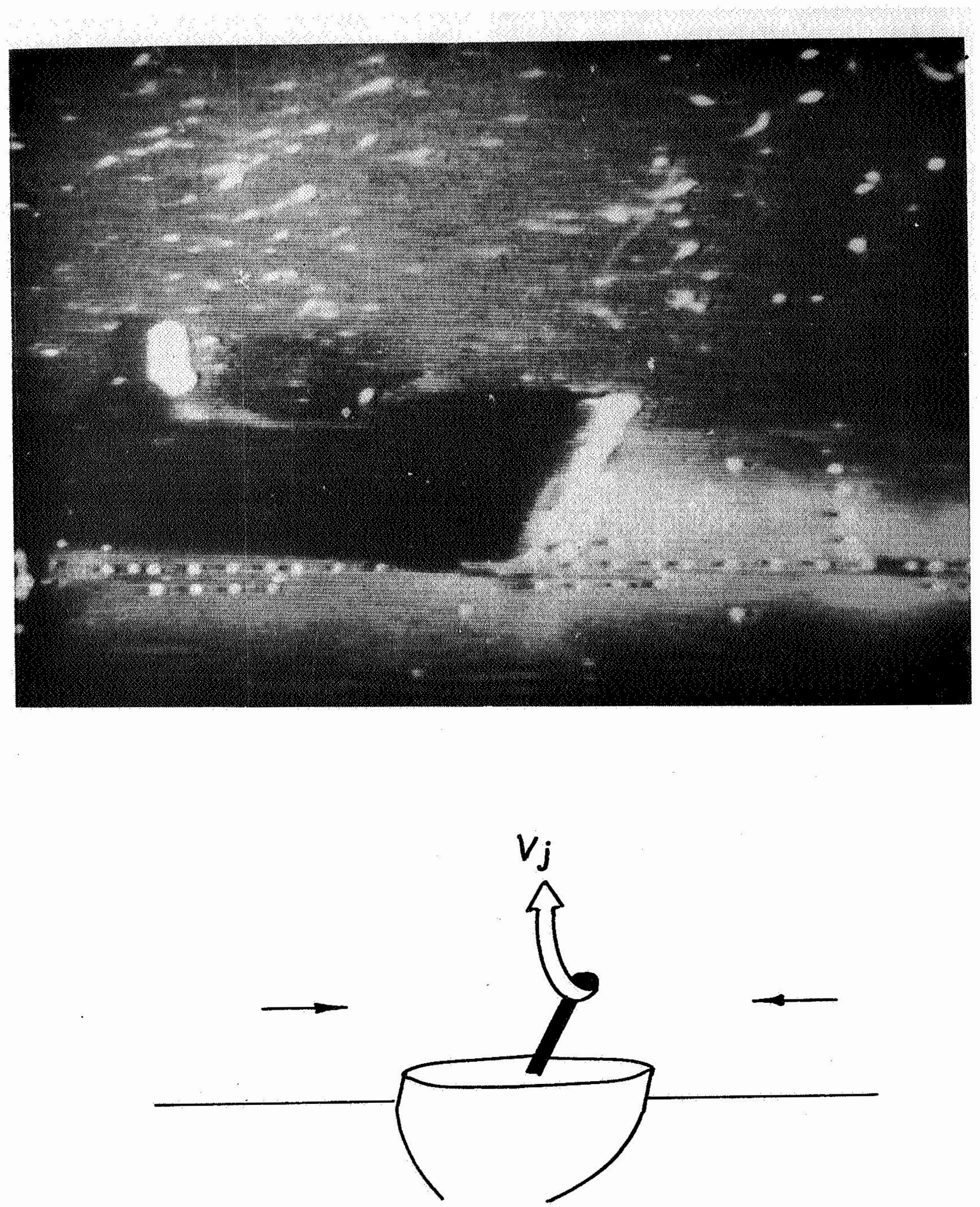

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Figure 19.- Swirl in exhaust entraining helium-filled soap bubbles.

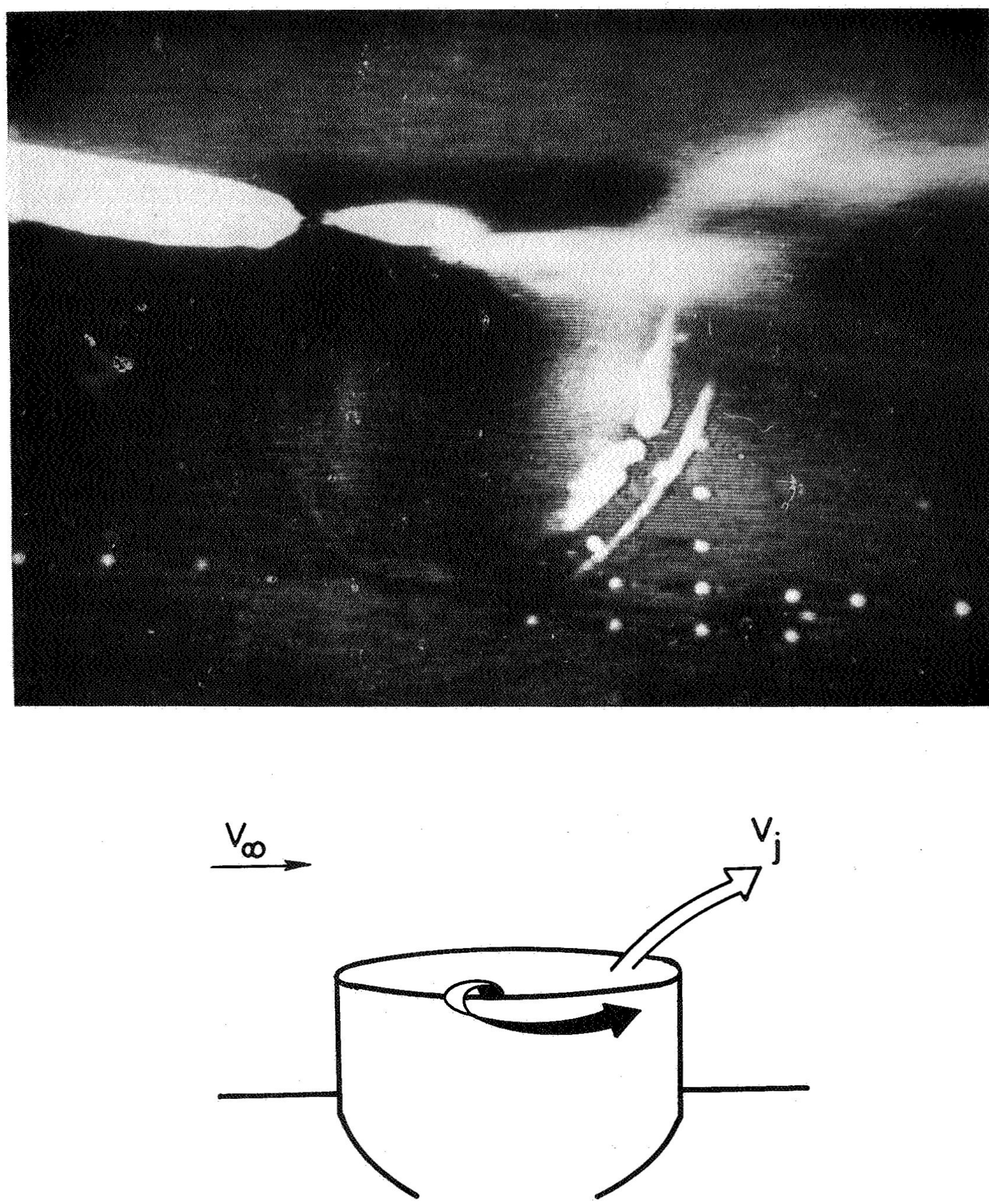

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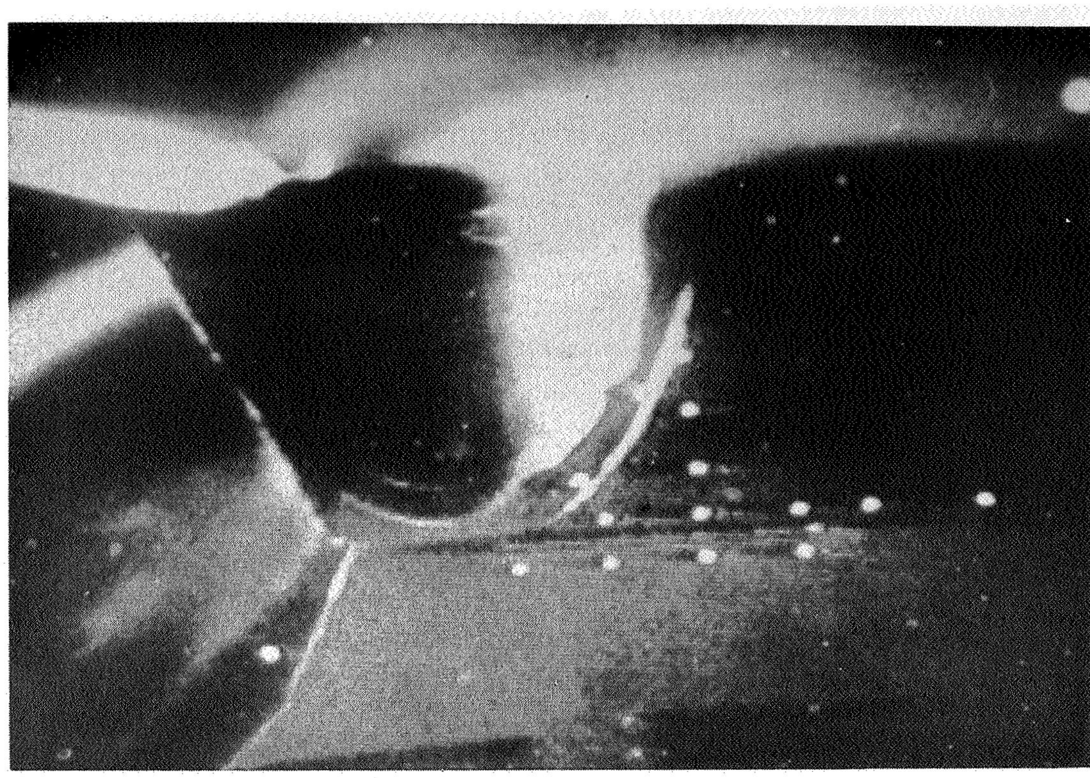
Figure 20.- Identification of flow mechanism causing heating problem (smoke pattern).



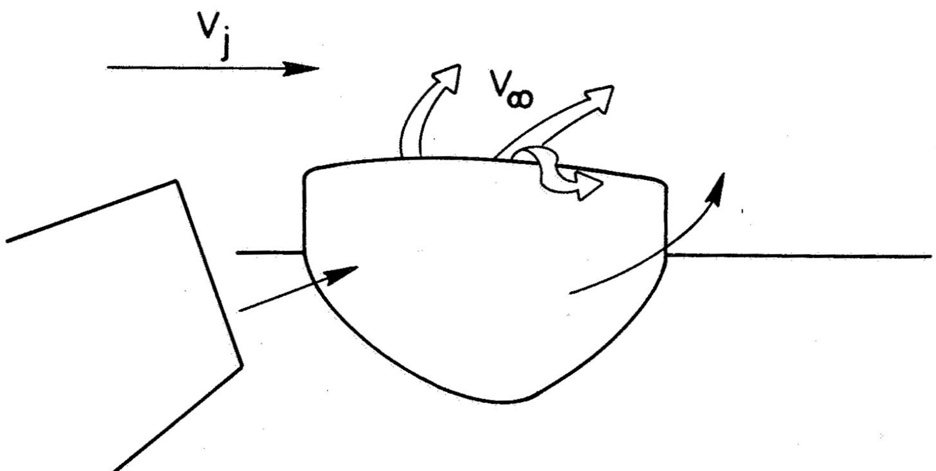


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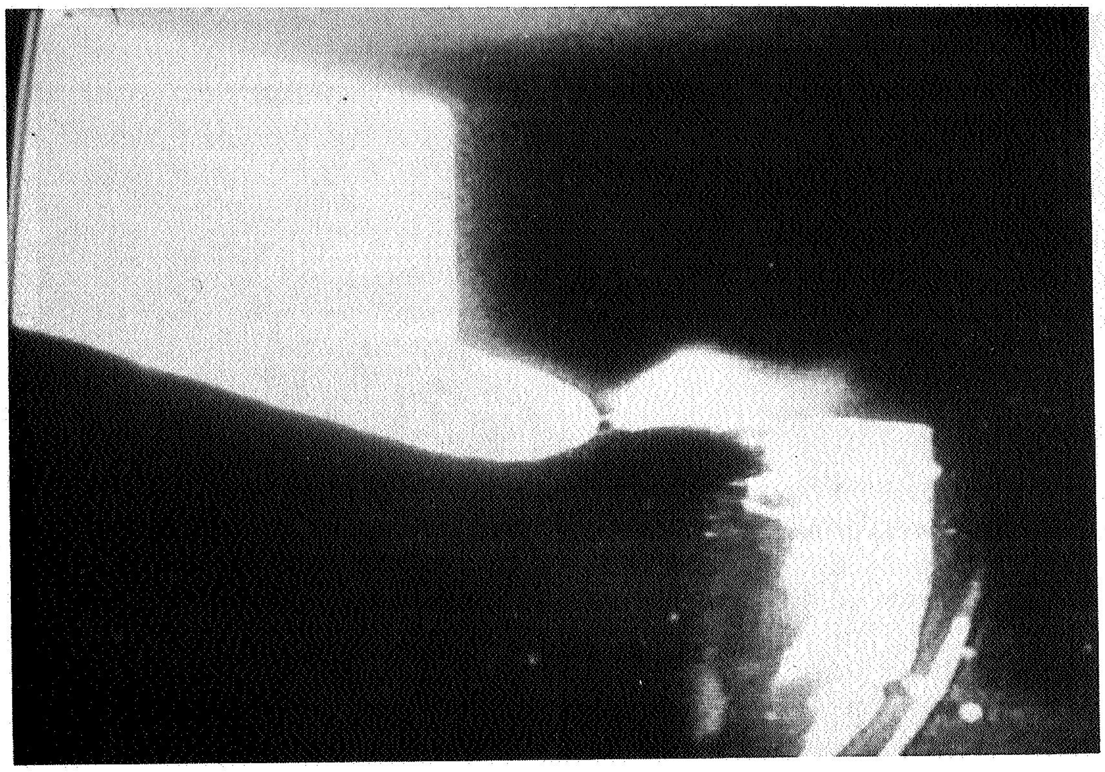
Figure 21.- Effect of flow control collar (smoke pattern).



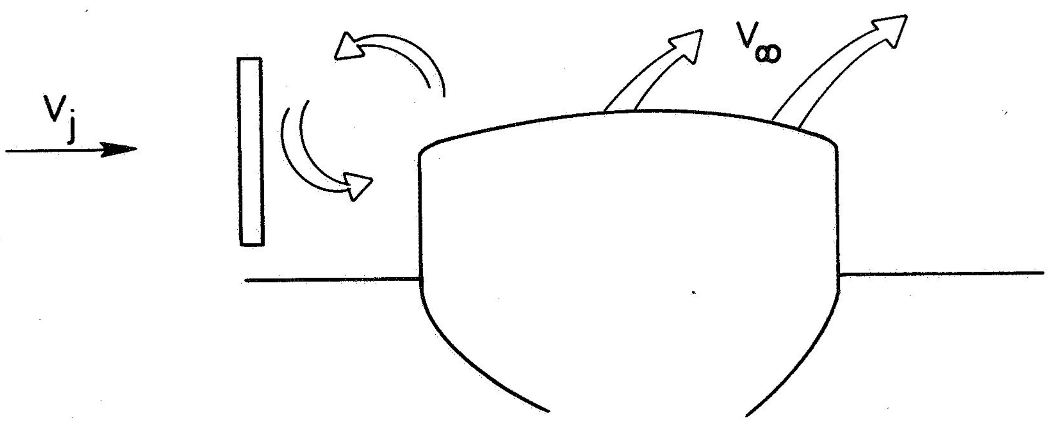


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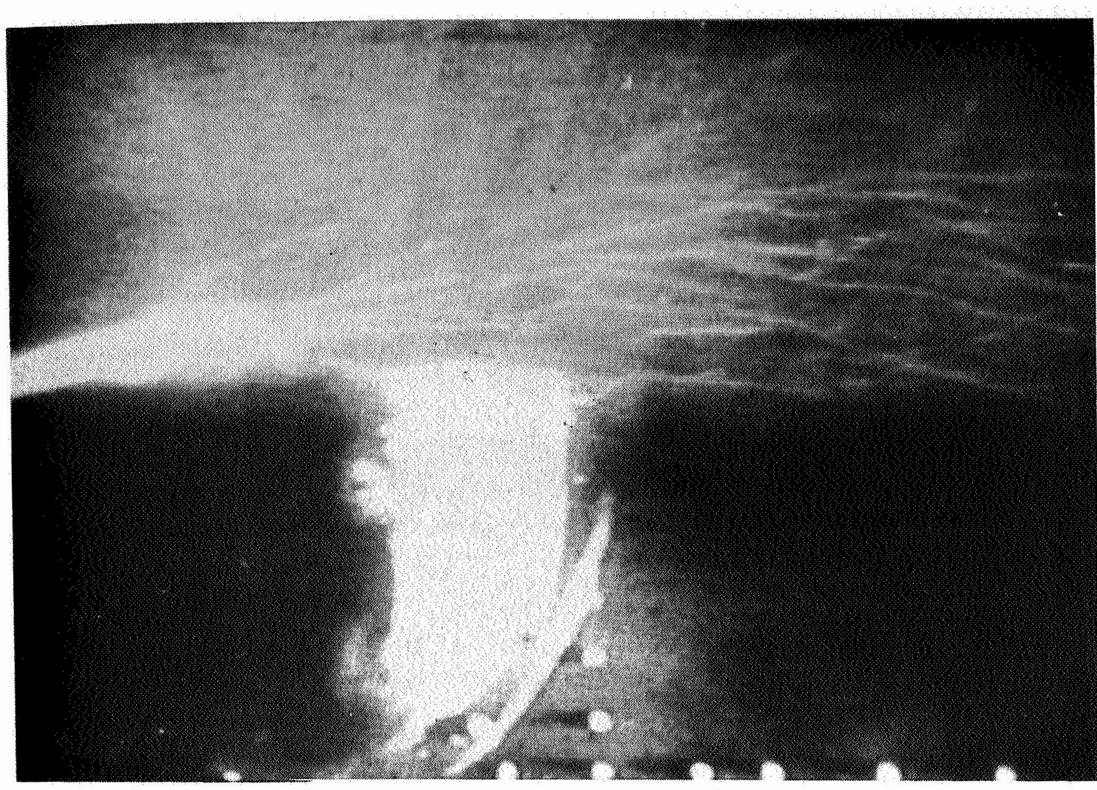
Figure 22.- Effect of flat plate (smoke pattern).



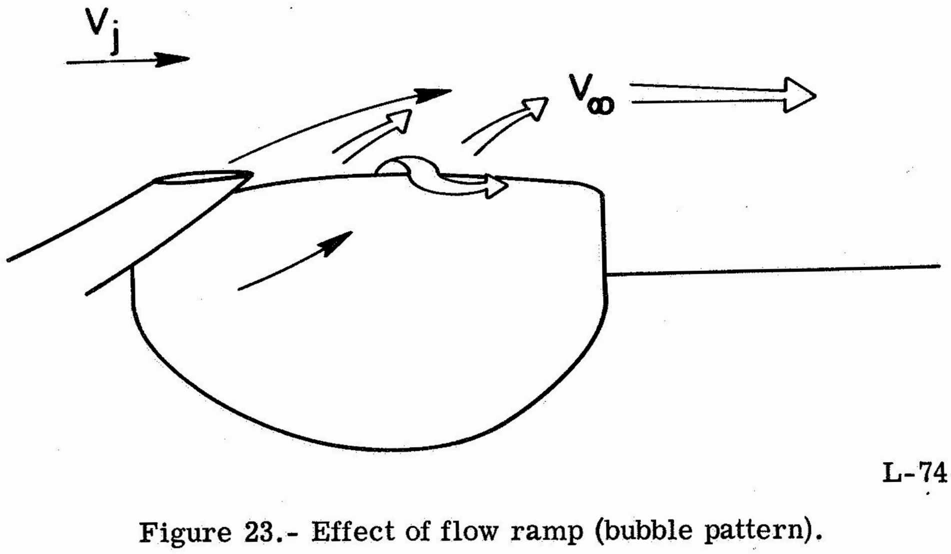


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Figure 23.- Effect of flow ramp (bubble pattern).

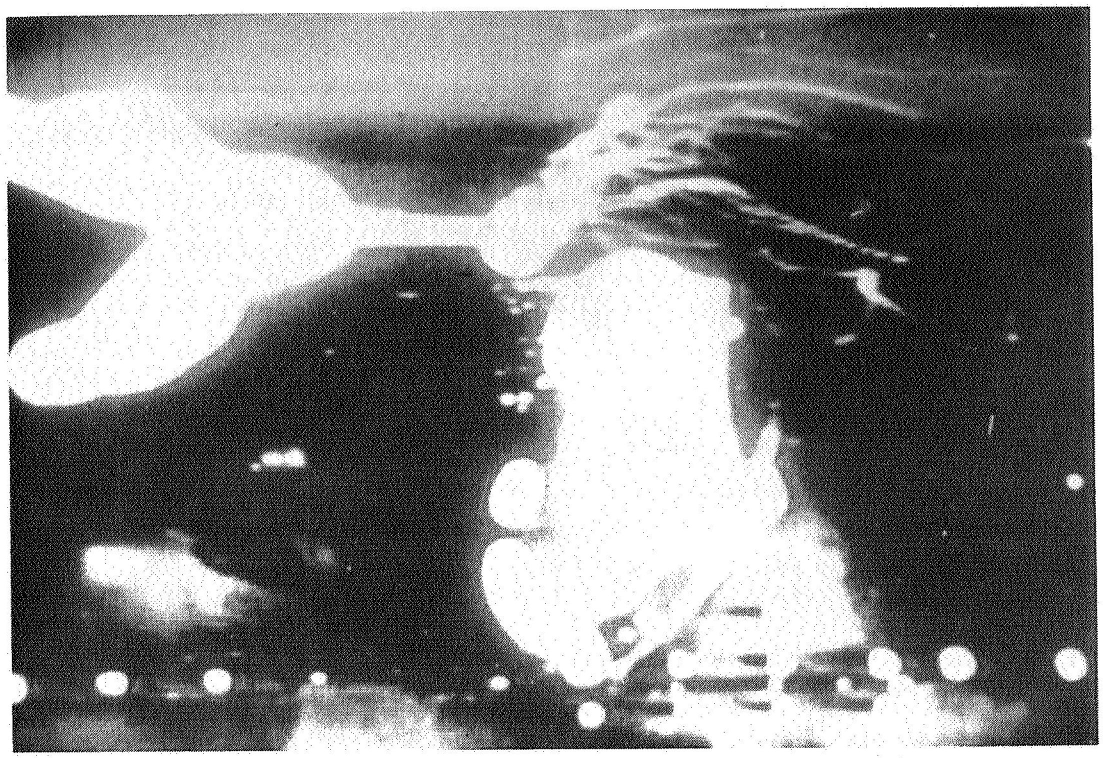

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Figure 24.- Effect of flow deflector (bubble pattern).

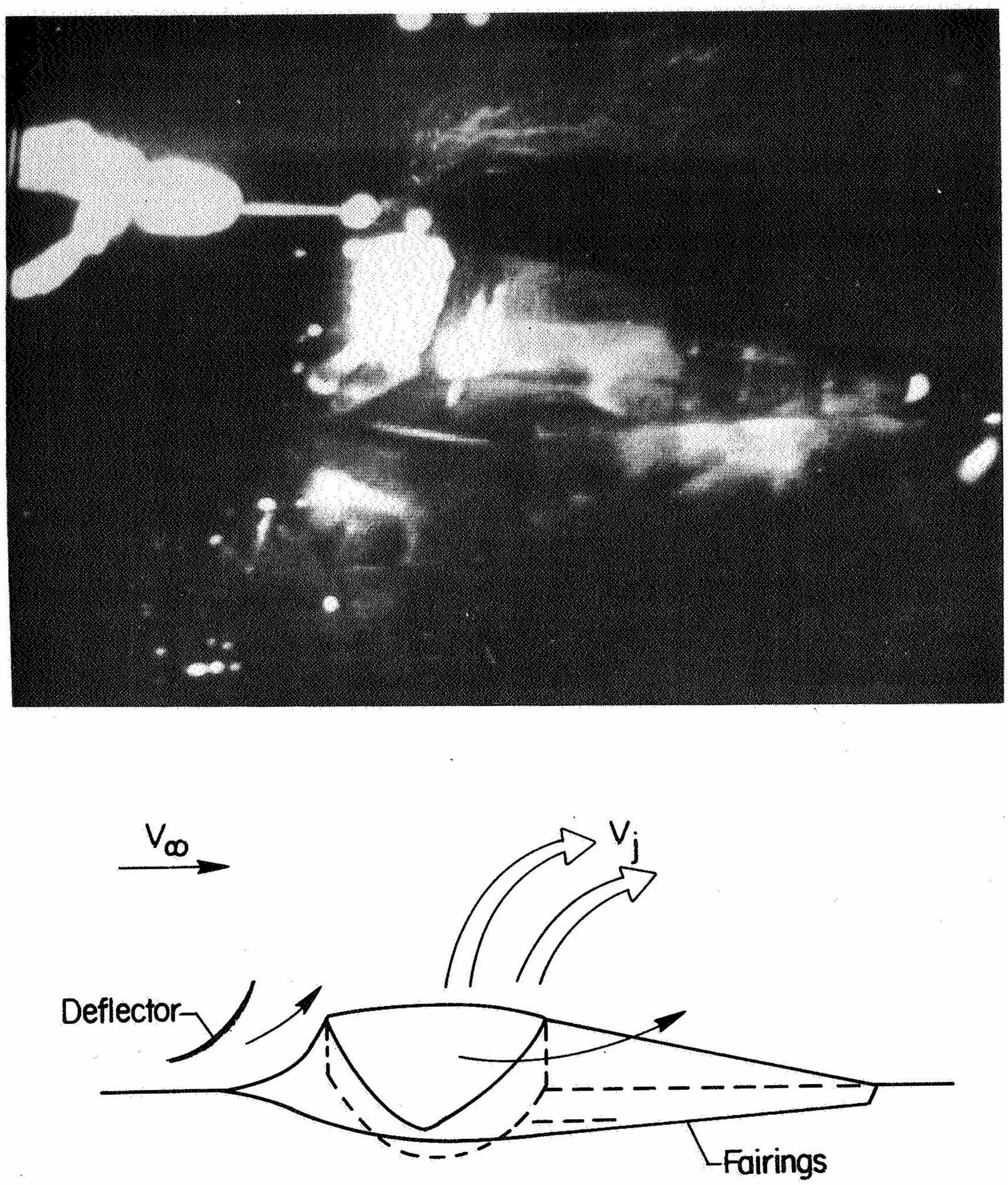

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Figure 25.- Effect of flow deflector and fairing (bubble pattern).

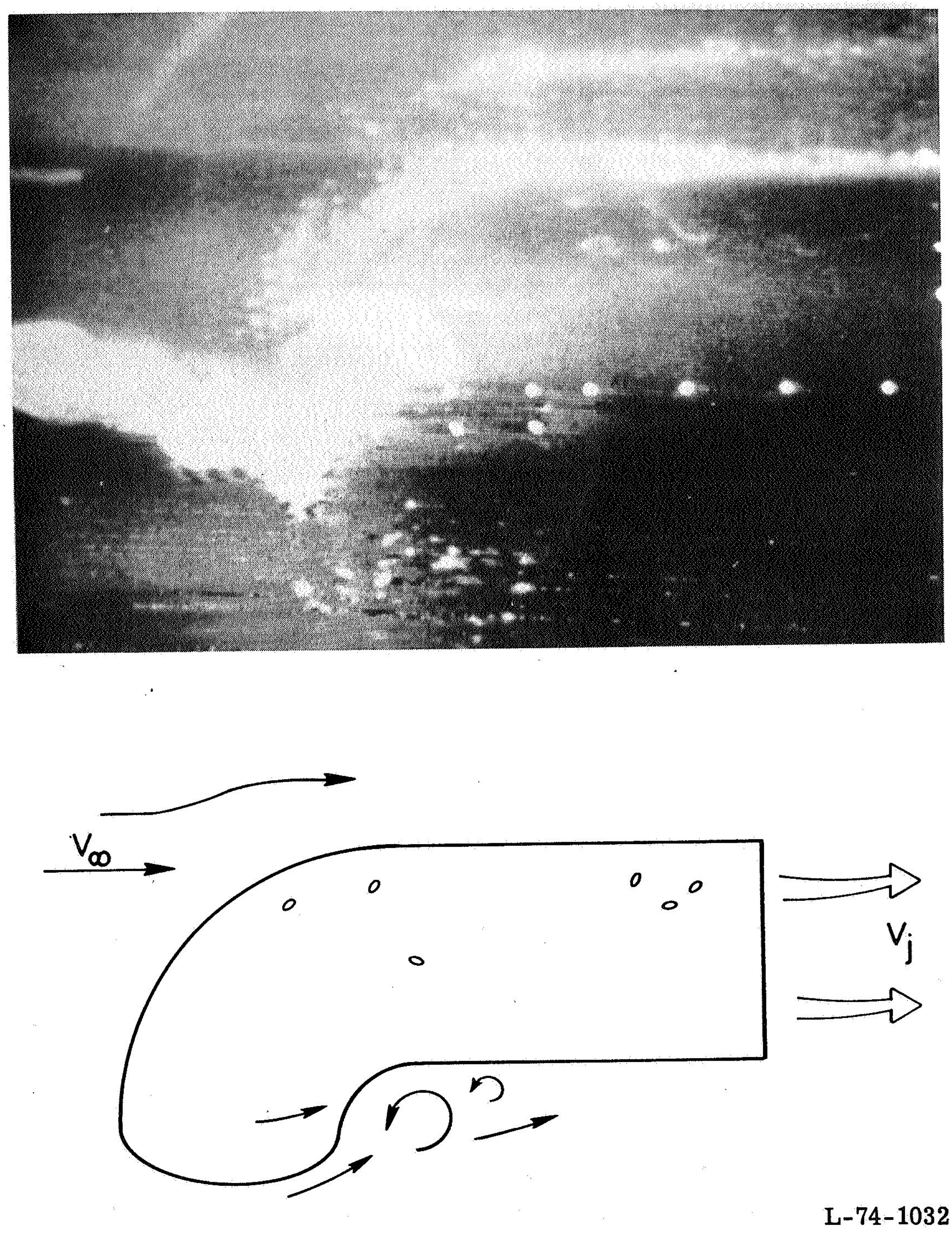

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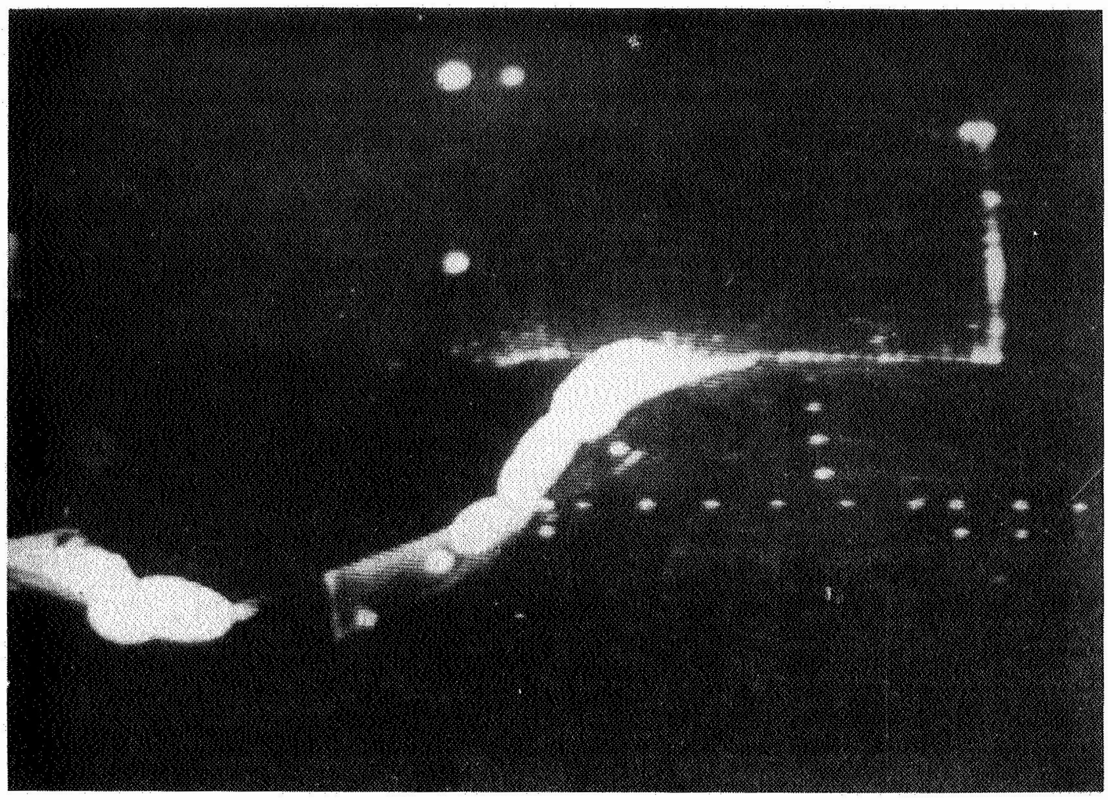
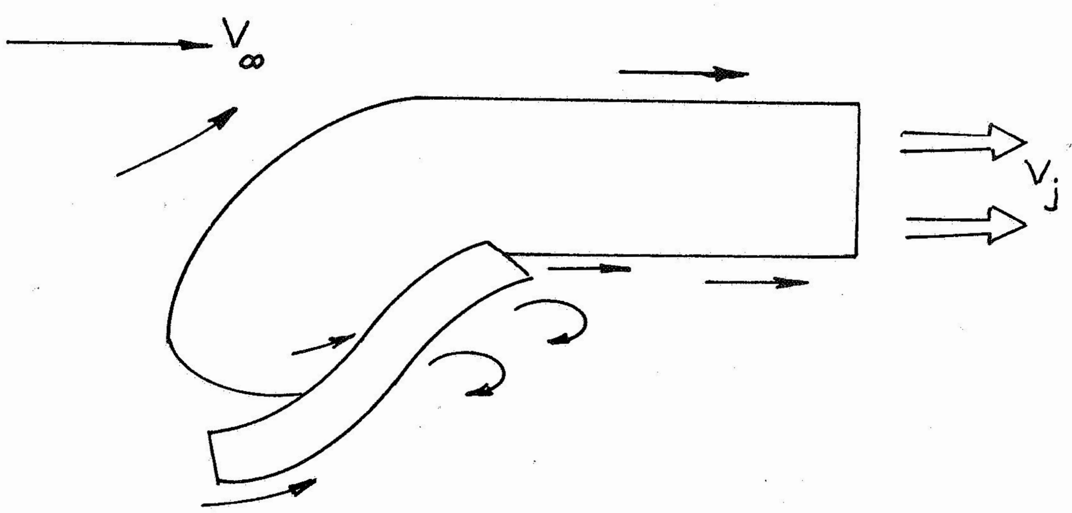
Figure 26.- Flow pattern around pin fin (smoke pattern).





L-74-1033

Figure 27.- Pin-fin with curved plate (bubble pattern).

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